(12) UK Patent Application (19) GB (11) 2 412 402 (13) A

(43) Date of A Publication 28.09.2005

(21) Application No: 0511012.7

(22) Date of Filing: 24.12.2001

Date Lodged: 28.05.2005

(62) Divided from Application No
0130852.7 under Section 15(4) of the Patents Act 1977

(51) INT CL[7]:
E04C 5/02

(52) UK CL (Edition X):
E1K K20C

(56) Documents Cited:
None

(58) Field of Search:
UK CL (Edition X) **E1K**
INT CL[7] **E04C**
Other:

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(54) Abstract Title: **Fibre reinforced concrete**

(57) Fibre reinforced concrete comprises thin steel wire of diameter between 0.05 and 0.3 mm in quantities up to 2.5% density. At least 30% of the fibres have an l/d ratio of 150 or more. To avoid the problem of balling when mixing, two alternatives are suggested. The first consists of strands of fibre, cut from recycled vehicle tyres. The second consists of a mixture of fibre lengths and thicknesses, giving a wide distribution of l/d ratios, which has the effect of reducing balling tendancy so that densities up to 1.5% can be achieved.

Figure 2

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Figure 1a

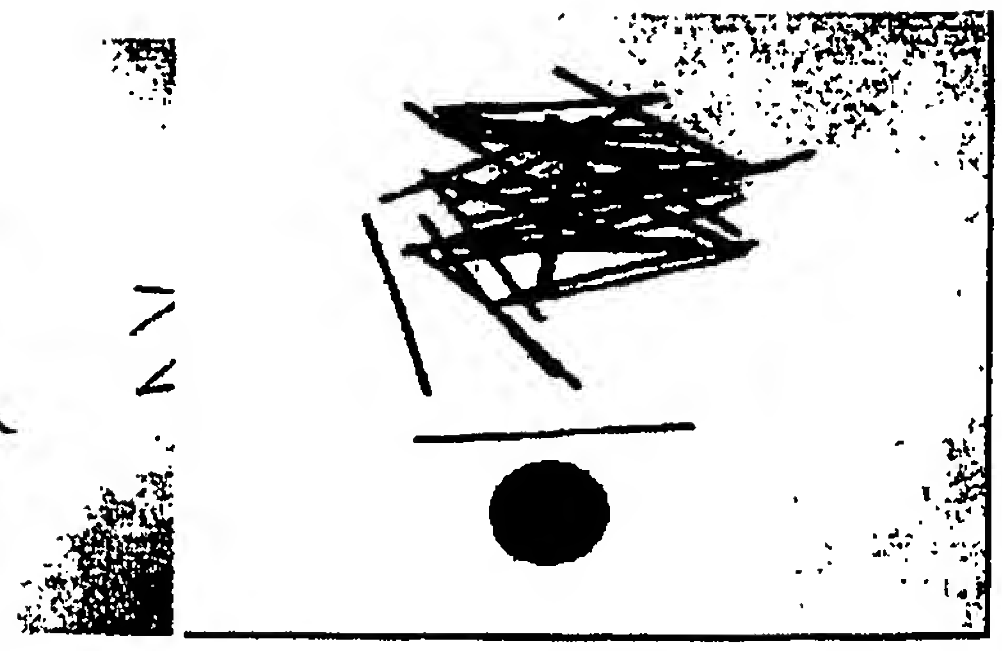

Figure 1b

Figure 2

Figure 3

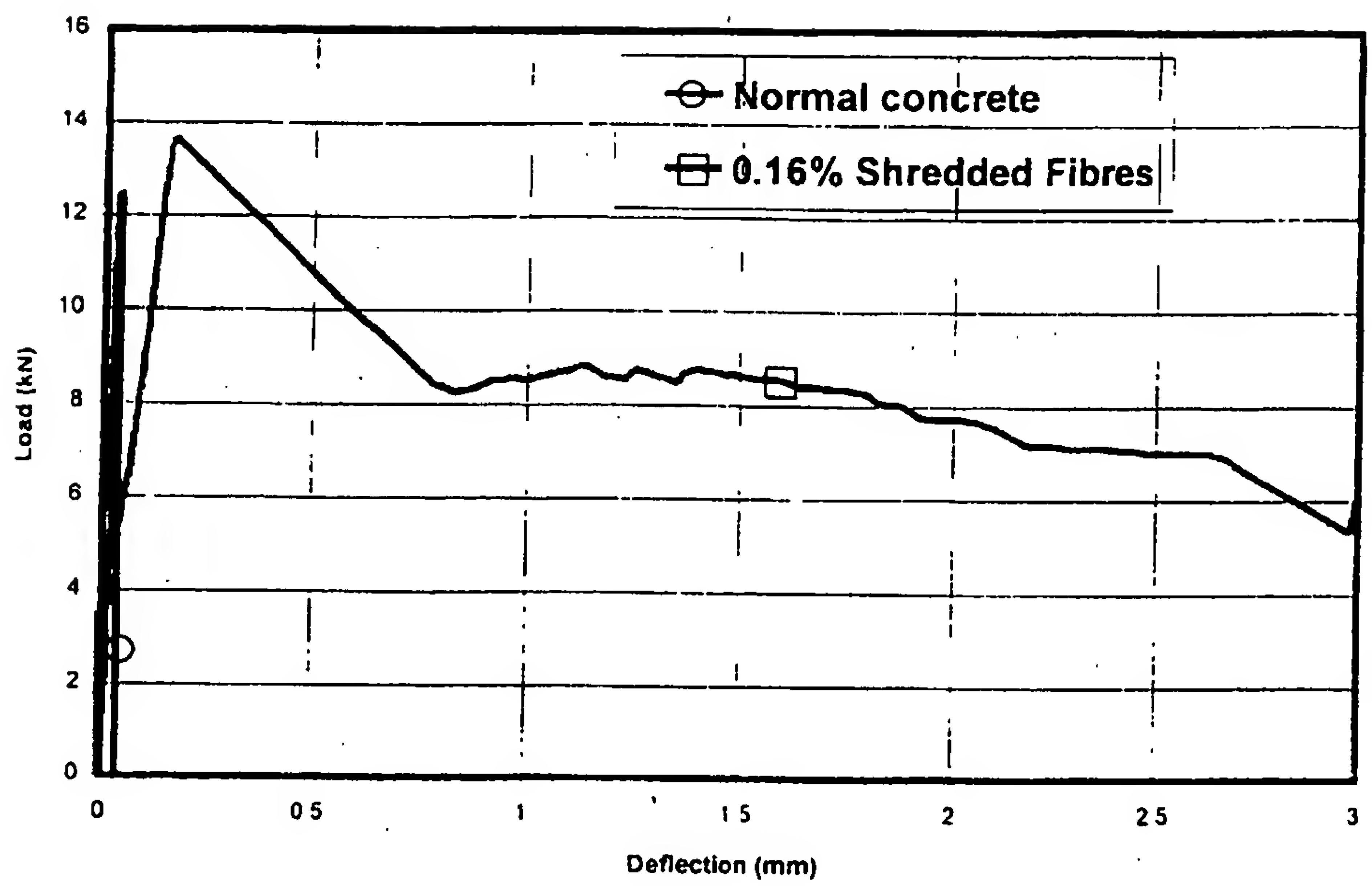
16
14
12
10
8
6
4
2
0
Load (kN)
Normal concrete
0.16% Shredded Fibres
0
0 5
1
1 5
2
2 5
3
Deflection (mm)

Fig. 4

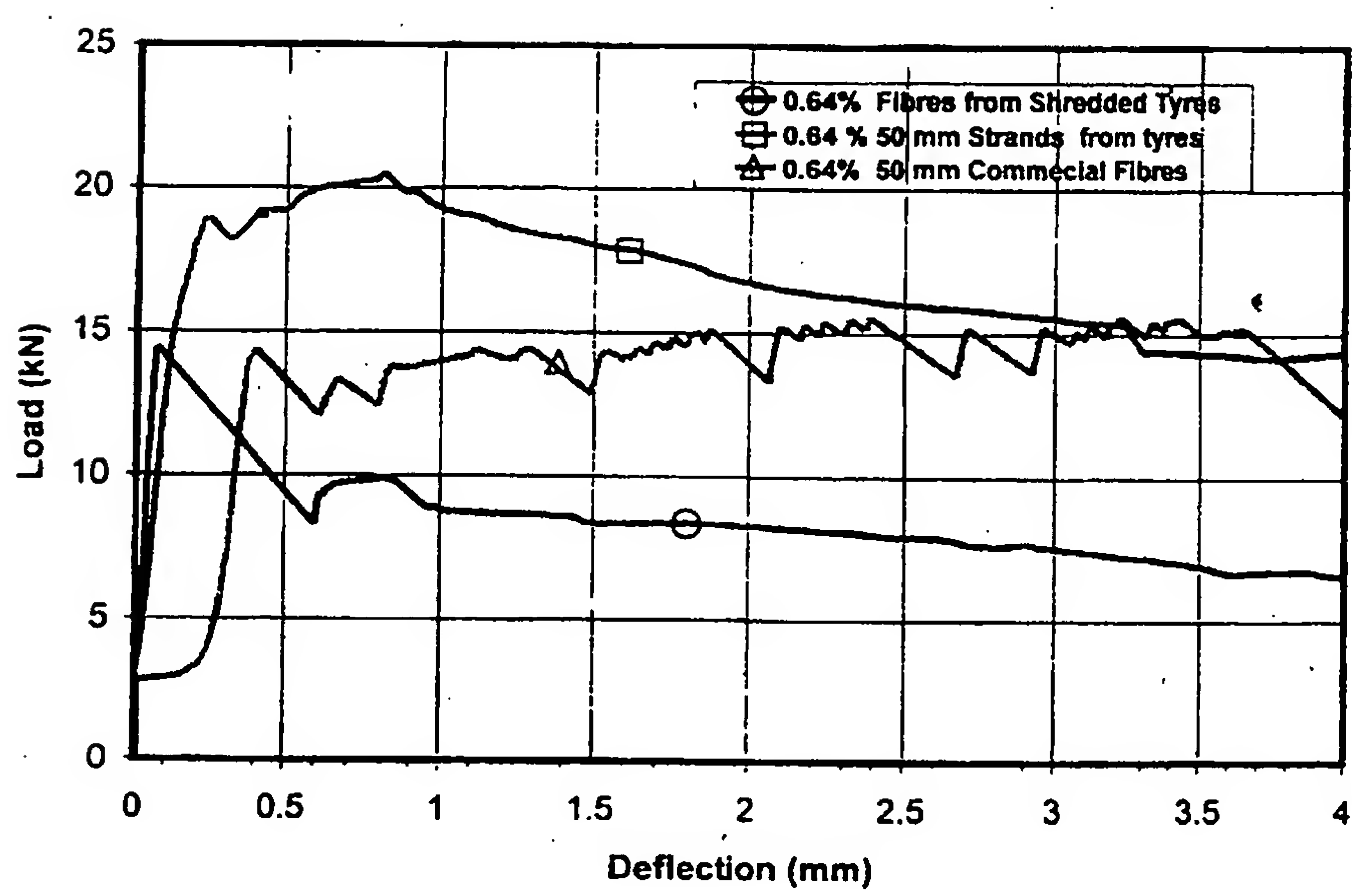
25
20
15
10
5
0
Load (kN)
0.64% Fibres from Shredded Tyres
0.64 % 50 mm Strands from tyres
0.64% 50 mm Commecial Fibres
0
0.5
1
1.5
2
2.5
3
3.5
4
Deflection (mm)

Fig. 5

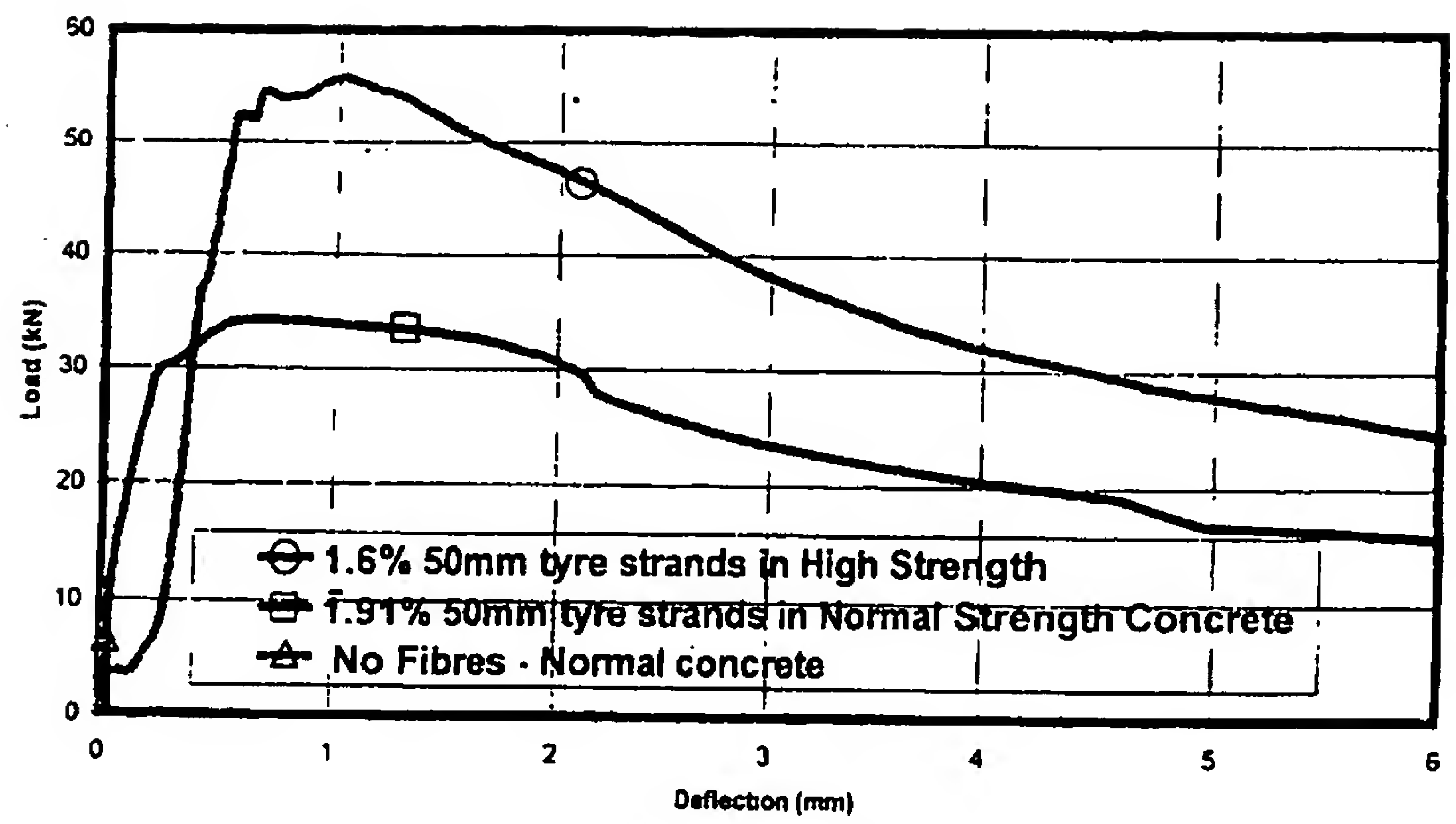
Load (kN)
Deflection (mm)
1.6% 50mm tyre strands in High Strength
1.91% 50mm tyre strands in Normal Strength Concrete
No Fibres - Normal concrete

Fig. 6

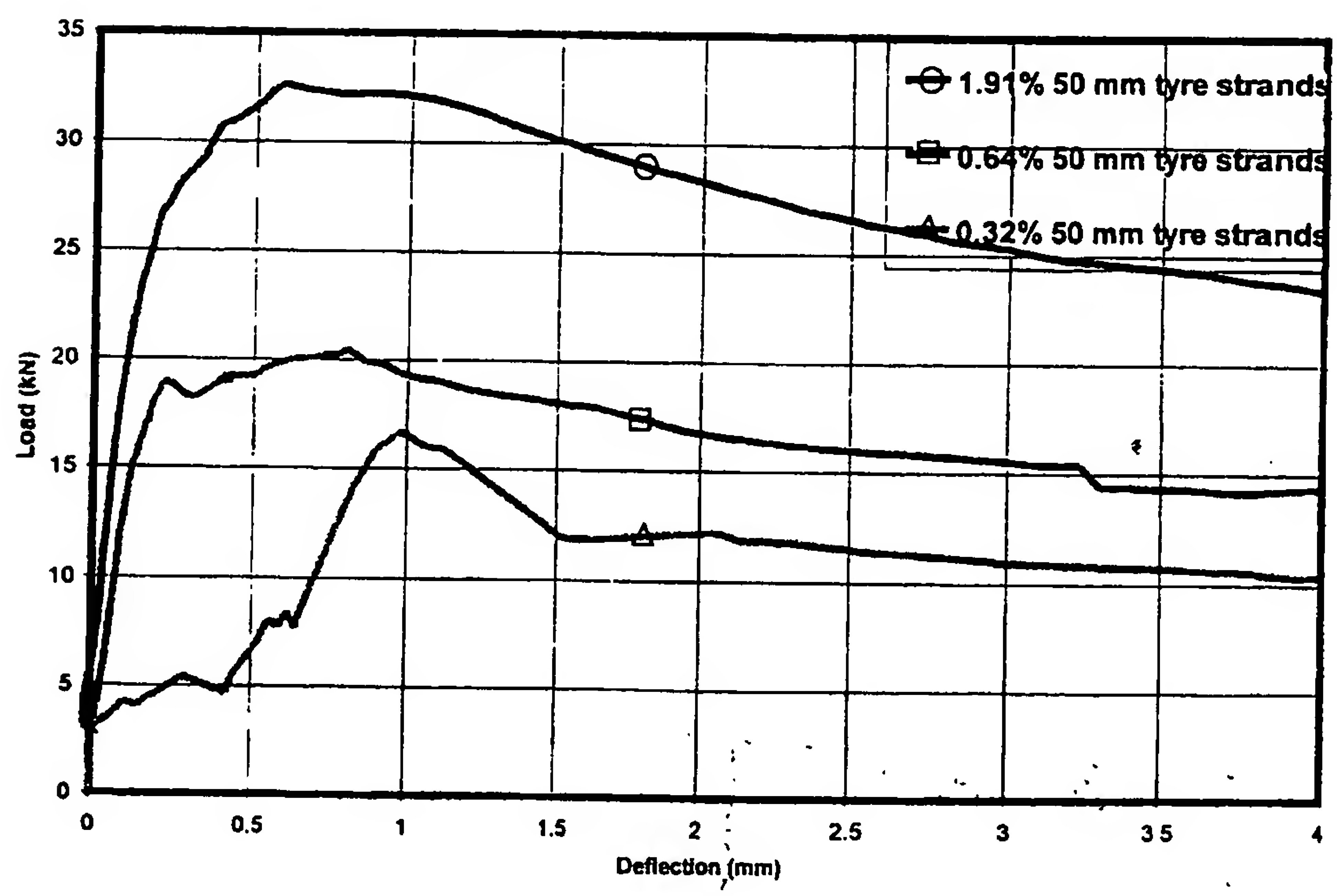
Load (kN)
Deflection (mm)
1.91% 50 mm tyre strands
0.64% 50 mm tyre strands
0.32% 50 mm tyre strands

Fig. 7

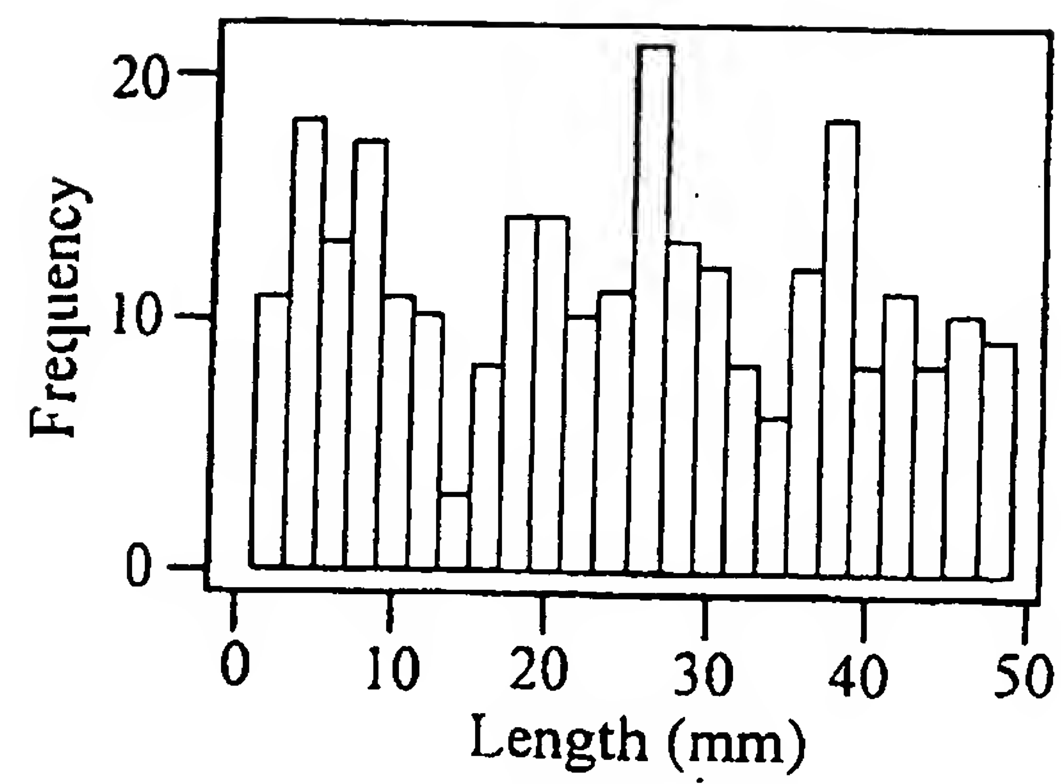

Fig. 8

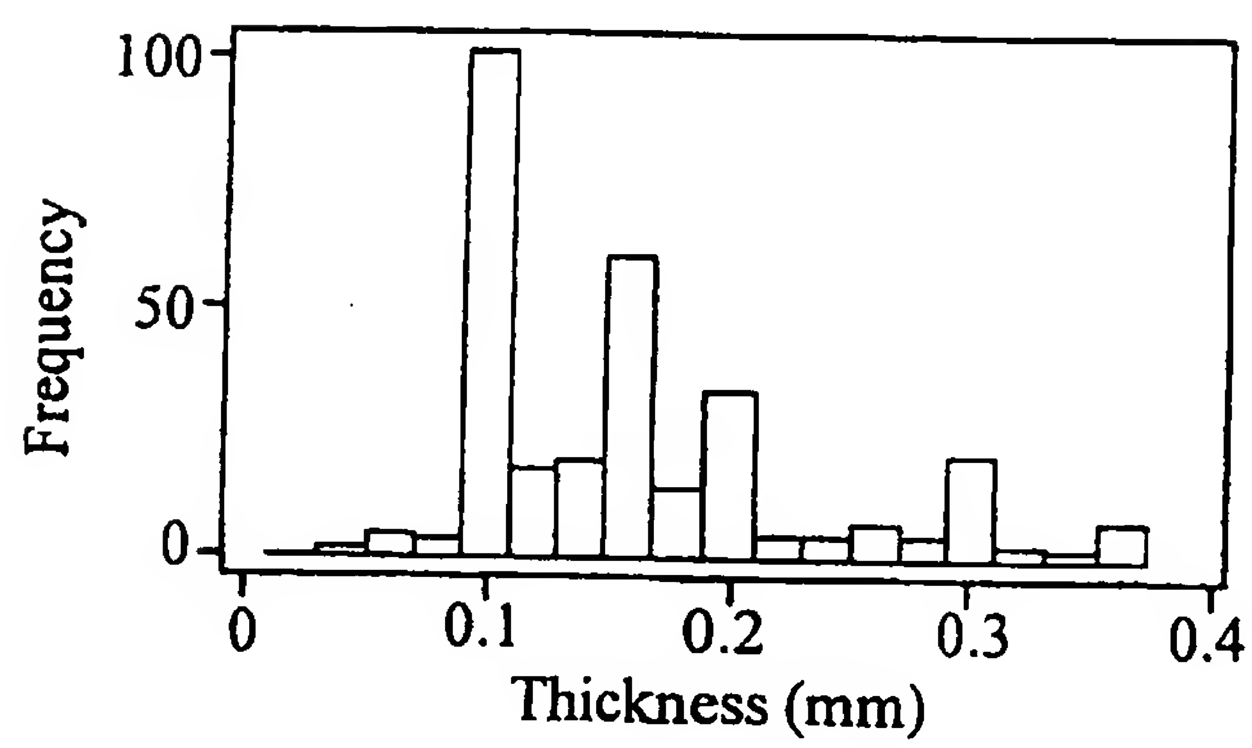

Fig. 9

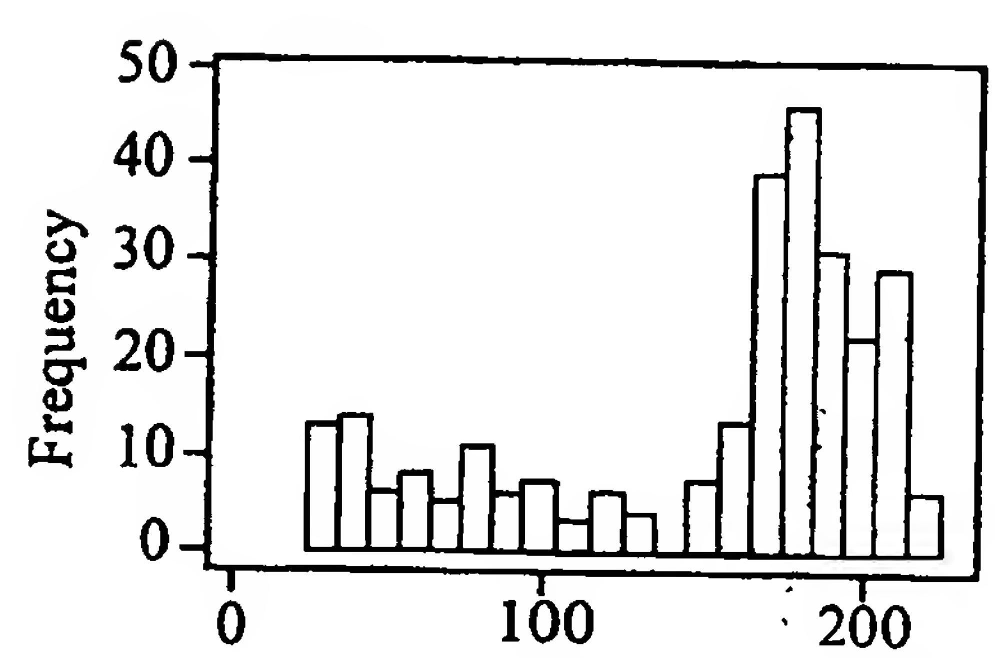

Fig. 10

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FIBRE REINFORCED CONCRETE

The present invention is in the field of fibre reinforced concrete.

It is known to reinforce concrete using steel cages of welded rods, or indeed individual rods tied together. It is known that these kinds of reinforcements present some problems, primarily because that type of reinforcement is on a "macro" level. Where concrete is required to be locally tough, or the geometrical shape to be reinforced is complex, such reinforcement is not very effective.

It is known to reinforce concrete using fibres, often of steel. Fibres are effective in reinforcing concrete locally, preventing cracking and surface deterioration, as well as providing structural reinforcement.

A problem with such fibres is that, if they are long and rigid (which, with steel, means having a length to diameter (l/d) ratio in excess of about 80, especially when volumes of fibres up to 2% are used) then the fibres tend to ball together and prevent even mixing and distribution of them throughout the concrete. Indeed, the more they are mixed, the tighter they ball together which, thereafter, prevents the concrete from being poured or pumped or cast, as is normally desirable with concrete.

It has been proposed to glue fibres together with water soluble adhesive. By such means, l/d ratios of the individual fibres of as much as 80 can be used even for fibre volumes higher than 2%. This is achieved because,

when the bundles of glued fibres are first introduced to the concrete mix, the bundles can be evenly distributed before the moisture in the cement and aggregate mix dissolves the adhesive. At this point the individual fibres separate from the bundle, but they need distribution then only over a local space. Relatively even distribution of the entire stock of fibres is thereby achieved before balling can start to occur.

However, even with this measure, performance is lacking in two key areas.

The first is simple, and this is that if fibre densities approach or exceed 2% by volume, mixing problems become an issue. From the latter perspective, it is more usual not to exceed ½%. Therefore, the reinforcement capacity of the fibres is limited.

The second problem is more complex. To be effective, the fibres must be anchored in the concrete. This is so that strain in the concrete is immediately shared by the reinforcement, "mobilising" the reinforcement to provide tensile support to the concrete to resist its cracking.

Steel presents a relatively "slippery" surface to concrete and, as a general rule, l/d ratios of the order of not less than 100, and ideally about 200 for high strength fibres, are needed to ensure complete mobilisation of the reinforcement. But with l/d ratios not exceeding 50, or at best about 80, such mobilisation cannot fully occur. For similar l/d ratios, smaller diameter fibres are more effective in transmitting loads.

This problem is overcome to some extent by kinking

the ends of fibres to form anchors (as disclosed in DE-A-4315270). This means that a crack developing across a fibre, even relatively near one end of the fibre, will transmit load to the fibre. However, the fibre becomes essentially free along its length (at relatively high stresses) within its sleeve of surrounding concrete because there is insufficient area of the fibre on which the concrete can bond. Consequently, the body of the fibre becomes unbonded and the stress is developed over the entire length of the fibre. This means that substantial strain must be imposed before the tension in the fibre balances, and counteracts, the stress in the concrete. This, in turn, means that a developing crack will widen more before it is halted. More, that is, than if, for example, a much shorter fibre spanned the crack while still being anchored at either end: the extension of such a short fibre would be much less for the same stress than a longer fibre.

Furthermore, using high tensile strength steel adds little benefit because the strength capacity of the fibre is substantially under utilised. At stresses at which such material would normally yield (that is, exploiting their full strength capability) the fibre would long previously have pulled itself out, even with the anchoring provided by a kinked end.

Consequently, not only can insufficient quantity of reinforcement be employed to provide adequate reinforcement (at least for more significant structural loads) but also the capacity of what is, or could be, employed cannot be fully exploited.

To address this problem many other solutions have been proposed, including modifying the surface of the fibre as

in US-A-5451471, DE-A-4242150, US-A-4960649, US-A-4804585, DE-A-3435850 or EP-A-105385, or modifying the cross section of the wire as in DE-A-1941223, US-A-4298660, or even using chains as JP1153563. All of these methods result in expensive reinforcement.

It is an object of the present invention therefore to provide a concrete reinforcement fibre composition and a concrete composition that does not suffer from, or at least mitigate the effects of, the aforementioned problems.

In accordance with the present invention there is provided a fibre reinforcement composition for concrete, comprising clean steel fibre of between 0.05 and 0.3 mm diameter, in which the fibres are provided in such a range of different lengths to diameter ratios that balling does not occur sufficiently to prevent mixing of the concrete to a satisfactory degree.

Preferably, more than 50%, and ideally more than 70%, by weight of the fibre has a l/d ratio greater than 150, substantially all of the remaining fibres being relatively evenly distributed in number frequency from an l/d ratio of about 150 down to about 30.

Said wire fibres may be generated by repeated shredding and shearing of car or other vehicle tyres, with subsequent extraction of mostly wire from the remaining fabric and elastomer.

By "clean" is meant less than 5% by volume rubber contamination of the fibres and sufficiently grease- and contamination- free to permit bonding of cement to the fibres.

With such thin wire, and such a large l/d ratio, secure bonding of the fibres in the concrete can be assured. This means that cracks open less before the stress is applied to the fibre which, over such a short length of it, tensions rapidly to balance the stress with only a small strain at the concrete crack. Consequently, the crack is not opened much, and so secondary effects such as environmental contaminant or moisture entry are minimised. Since more secure bonding is achieved, higher stresses can be absorbed, thereby more efficiently utilising the full strength capacity of the fibre.

The problem of balling or clumping with the high l/d ratio fibres is overcome by providing the fibres in such a range of different lengths to diameter ratios that balling does not occur sufficiently to prevent mixing of the concrete to a satisfactory degree.

Surprisingly, it is found that a distribution of fibres having a smaller l/d ratio size prevents balling, or rather reduces the tendency to ball when compared with a corresponding density of fibre where substantially all the fibres have an l/d ratio of above 150. Consequently high l/d ratio fibres can be included in concrete to densities of about 1.5%. Thus, tough fibre-reinforced concrete can be made wherein the reinforcement is used to its maximum extent.

Such a distribution of wire fibres can be generated by repeated shredding and shearing of car or other vehicle tyres with subsequent magnetic extraction of the wire from the remaining fabric and elastomer.

Indeed, it is an aspect of the present invention

that it provides an outlet for the recycling of vehicle tyres and an inexpensive source of effective reinforcement for concrete. DE-A-4104929 discloses using wire from tyres, but mixes rubber-bound-fibre mixed with non-flammable concrete components, the rubber being burnt off prior to cooling and adding of cement and water.

An important aspect of the present invention is the mix of the concrete. That is to say, the size distribution and makeup of the aggregate, as well as the type of cement, all have an impact on the tendency of the fibre element to ball when it is mixed. Generally, an increase in fines reduces balling, but it remains that some trial and error might be required to find satisfactory mixes that achieve the aims of the present invention, at least in its second embodiment.

In both embodiments of the invention, the fibres could be used to produce (a) SIMCON (Slurry Infiltrated Mat Concrete), (b) SIFCON (Slurry Infiltrated Fibre Concrete), and (c) high-strength, high performance concrete.

SIMCON is particularly suited to the second embodiment of the present invention, since a very thin mat (similar to glass fibre chopped strand mat) can be used to create thin structural elements of thickness not exceeding a few millimetres. SIMCON is also suitable for near surface reinforcement of thicker elements. The thin mat of fibres can be produced preferably by using polymer adhesives or welding or stitching of the steel fibres.

SIFCON can be produced with both embodiments of the present invention, in a much more economic way than with current systems, especially when recycled fibres from

tyres are used.

The invention is further described hereinafter with reference to the following examples, in which types of concrete are prepared as follows:

Example I - A Typical Normal Concrete

Total Weight	100
Ordinary Portland Cement	16.5
Water	7.5
Fine Aggregate	30
Coarse Aggregate (Crushed River Aggregate <20 mm)	46
Water/Cement ratio	0.45

Example II - A High Strength Concrete

Total Weight	100
Ordinary Portland Cement	15.4
Type of pulverised fuel ash	4.4
Micro-silica	4.4
Water	3.5
Fine Aggregate	29.7
Coarse Aggregate (Crushed River Aggregate <20 mm)	42.6
Superplasticizer	1.5 % (Weight of Cement)
Water/Cement ratio	0.23

Materials used

Ordinary Portland Cement

An ordinary portland cement (OPC) type I, manufactured by Rugby Cement Group: in accordance with BS 12: 1996, class 42.5N, was used through the study. The

typical chemical and physical properties of the cement are given in Table 1.

Table 1. Chemical and physical properties of the OPC used

Chemical Composition	**Percentage**	**Physical Properties**
Silica SiO_2	20.5-21.8	Relative density: 3.1
Alumina AlO_3	5.1	Theoretical surface area: 3800 m^2/kg
Iron Fe_2O_3	3.7	pH in water N/A
Calcium CaO	64.6	Moisture content N/A
Magnesium MgO	1.3	Comp strength EN 196-1 Mortar Prisms
Sulphate SO_3	2.3-3.1	3 days 20.6-21.6 N/mm^2
Alkalis	0.57-0.74	7 days 34.8 N/mm^2
Chlorides Cl^-	<0.02	28 days 42.6-43.4 N/mm^2

<u>Aggregates</u>

The aggregate used (both coarse and fine) was fluvial dragged gravel. The shape of the aggregate was rounded, fully water-worn or completely shaped by attrition, i.e. river or seashore gravel; desert, seashore and wind-blown sand. The surface texture was smooth, water-worn, or smooth due to fracture of laminated or fine-grained rock, i.e. gravels, chert, slate, marble, some rhyolites. These classifications are made according to BS 812: Part 1:1975. The aggregate grading was made according to the BS 812: Part 1:1975, the results of this grading are shown in the Table 2, and Table 3. Other properties are given in Table 4.

Table 2. Coarse aggregate grading

Sieve size (mm)	20 mm aggregate Passing (%)	10 mm aggregate Passing(%)
37.5	100	100
20	98	100
14	57	100
10	12	95
5	05	7
2.36	-	0.65

Table 3. Fine aggregate grading

Sieve size (mm)	Fine aggregate sands Passing (%)
9.5	100
4.75	98
2.36	88
1.18	80
0.6	68
0.3	23
0.15	4
0.075	0.5

Table 4. Other Material Data

	Density	Water Absorption	Water Content
OPC	3150		
Sand	2590	0.59	0.10
C. Agg. (20)	2600	0.58	0.09
C. Agg. (10)	2600	0.60	0.34

Steel Fibres

Fibres from Shredded Tyres

The fibres used to make the concrete of the present

invention were obtained from the shredding process, dealing primarily with a mixture of truck tyres. The fibres were not completely free of rubber, having around 10% rubber by weight. The fibres used had the following properties in terms of length (L), thickness (D) and l/d ratio. The strength of the fibres varied from 2000 MPa to 3000 MPa.

The invention is further described hereinafter, by way of example, with reference to the accompanying drawings, in which:

Figure 1a and b are photos of stranded wire derived from the Amat process, in Figure 2a, the strands being separated into their individual fibres, whereas in Figure 2b the strands are intact (not part of the present invention);

Figure 2 shows fibres from shredded tyres prior to further cleaning and sorting;

Figure 3 is a photo of a concrete sample demonstrating adequate workability;

Figure 4 is a graph showing deflection of a concrete sample according to Example I above with, and without, shredded fibres of the present invention;

Figure 5 is a similar graph comparing the present invention with an alternative using fibre strands of Figure 1, in concrete from Example I, and also comparing with the same concrete employing presently available commercial fibres;

Figure 6 compares normal concrete with no fibres, normal concrete with tyre strands, and high strength concrete of Example II, with tyre strands(not part of the present invention);

Figure 7 compares increasing density of tyre strands in concrete of the Example I(not part of the present

invention);

Figure 8 shows the length distribution of fibres from shredded tyres;

Figure 9 shows thickness distribution of fibres in accordance with the present invention; and

Figure 10 shows the length to diameter ratio distribution of fibres according to the present invention.

The steel fibres of Figures 1 and 2 were prepared as described above and mixed with two examples of concrete mix as also described above, and in various densities of fibre to concrete, as indicated in Figures 4 to 7. To demonstrate workability, the concrete and fibre mix is poured into an open-ended cone, visible in Figure 3. When the cone is lifted, the slump of the concrete indicates the workability of the concrete and hence its capacity to flow when pumped or poured into the requisite mould. Depending on the degree of workability required, the density of fibre is adjusted accordingly.

With reference to Figures 4 to 7, standard concrete blocks are formed and cured and subjected to increasing load while the deflection of the sample is monitored. In Figure 4, it can be seen that, for normal, unreinforced concrete, load increases with minimal deflection up to a maximum point at which fracture occurs. However, with only 0.2% of shredded fibres, (in accordance with the present invention), substantial deflection of the sample occurs while still supporting a load.

In Figure 5, 0.8% density of fibres were included in three samples of normal concrete in accordance with Example I above. In the first sample, the fibres were in accordance with this invention, namely from shredded

tyres. In the second sample, the fibres were from a commercially available source (Novocon). The third sample comprised fibres in the form of strands. It can be seen that the sample employing starnds exhibited the greatest loads and deflections, while the sample according to the invention quite acceptable loads.

Figure 6 demonstrates the substantial loads that are accommodated with high strength concrete (according to Example II above) compared with normal strength concrete (according to Example I above).

Figure 7 demonstrates the increasing loads capable of accommodation with increasing density of fibre strands.

Finally, in Figures 8 to 10, it can be seen that the distribution of fibres employed in the examples according to the invention have a wide distribution of lengths and four main thicknesses. This results in a length to diameter distribution in which the vast majority of the fibres, both in terms of number and weight per cent have an l/d ratio in excess of 150. However, it is the small proportion of fibres having both a smaller and widely varying l/d ratio that render the samples workable without substantial balling.

CLAIMS

1. A fibre reinforcement composition for concrete, comprising clean steel fibre of between 0.05 and 0.3 mm diameter, in which the fibres are provided in such a range of different lengths to diameter ratios that balling does not occur sufficiently to prevent mixing of the concrete to a satisfactory degree.

2. A composition as claimed in claim 1, in which more than 50% by weight of the fibre has a l/d ratio greater than 150, substantially all of the remaining fibres being relatively evenly distributed in number frequency from an l/d ratio of about 150 down to about 30.

3. A composition as claimed in claim 2, in which more than 70% by weight of the fibre has an l/d ratio greater than 150.

4. A composition as claimed in claim 1, 2 or 3, in which said wire fibres are generated by repeated shredding and shearing of car or other vehicle tyres, with subsequent extraction of mostly wire from the remaining fabric and elastomer.

5. Concrete comprising a composition as claimed in any preceding claim in which the composition comprises at least 1.5% by weight of the concrete.

6. A fibre reinforcement composition as claimed in claim 1, substantially as hereinbefore described with reference to Figures 2, 4, 5, 8, 9 and 10 of the accompanying drawings.

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INVESTOR IN PEOPLE

Application No: GB0511012.7 **Examiner:** Sarah Harrison

Claims searched: 1-6 **Date of search:** 22 July 2005

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
		None

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

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E1K

Worldwide search of patent documents classified in the following areas of the IPC^{07}

E04C

The following online and other databases have been used in the preparation of this search report

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